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An Overview of Computational Simulation Methods for Composite Structures Failure and Life Analysis

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PRESENTATION OUTLINE

- Background
- Objective
- Progressive Fracture in Polymer Composite Structures
- Hierarchical Simulation of Failure/Life in High Temperature Composite Structures
- Probabilistic Evaluation of Composite Structural Failure/Life/Reliability

BACKGROUND

Computational simulation methods for composite structures integrity, durability, failure and life analysis have been an on-going activity in the Structural Mechanics Branch at Lewis over the past two decades.

Recent activity focus is on three parallel methods to simulate structural failure, life and reliability:

- Progressive fracture - polymer composite
- Hierarchical simulation - high temperature composites
- Probabilistic evaluation - polymer composites

OBJECTIVE

Provide a brief overview of these recent activities with some typical results.

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CODSTRAN ANALYSIS CYCLE

Progressive fracture in composite structures must include simulation of the (1) composite behavior in all its scales and respective failure modes (14 per ply and its adjacent interplies), (2) complex structural configurations with various loading conditions and boundary conditions, (3) hygrothermal environments, (4) synthesis of the composite structural behavior from micromechanics to global response, and (5) decomposition of the composite global structural response. All of these are incorporated in CODSTRAN as illustrated in Fig. 1.

Reference: Minnetyan, L., Chamis, C. C. and Murthy, P. L. N., "Damage and Fracture in Composite Thin Shells," NASA TM 105289, October 1991.

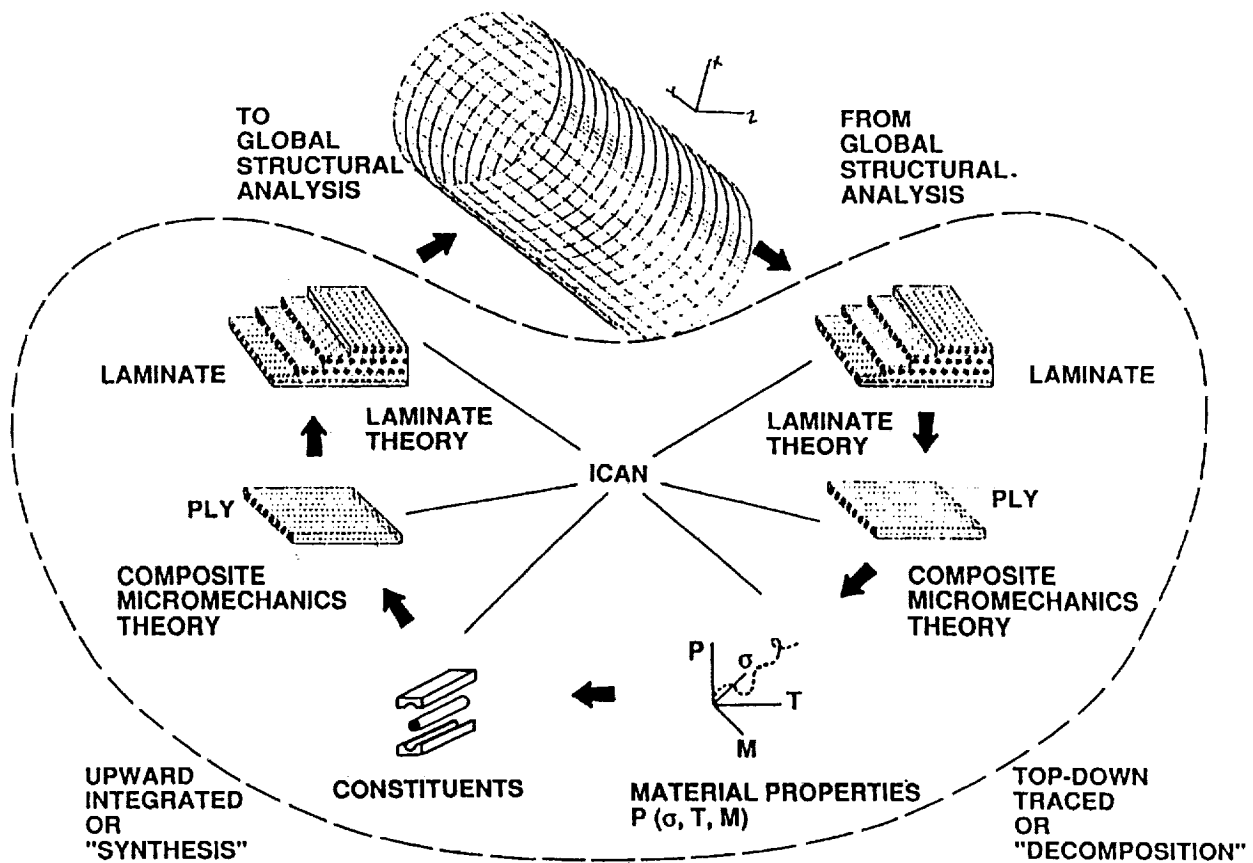


Figure 1 - Codstran Analysis Cycle Schematic

CODSTRAN LOAD INCREMENTATION

An incremental progressive fracture strategy is employed in CODSTRAN as illustrated in Figs. 2 and 3. Thermal and hygral loads are handled the same way as are cyclic and dynamic loads. Imposed displacements are also handled the same way.

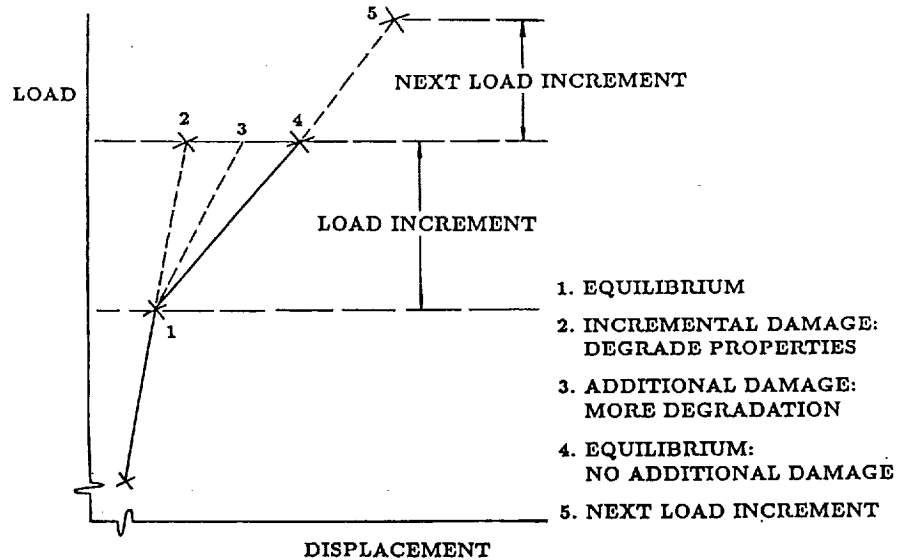


Figure 2 - Codstran Load Incrementation Schematic

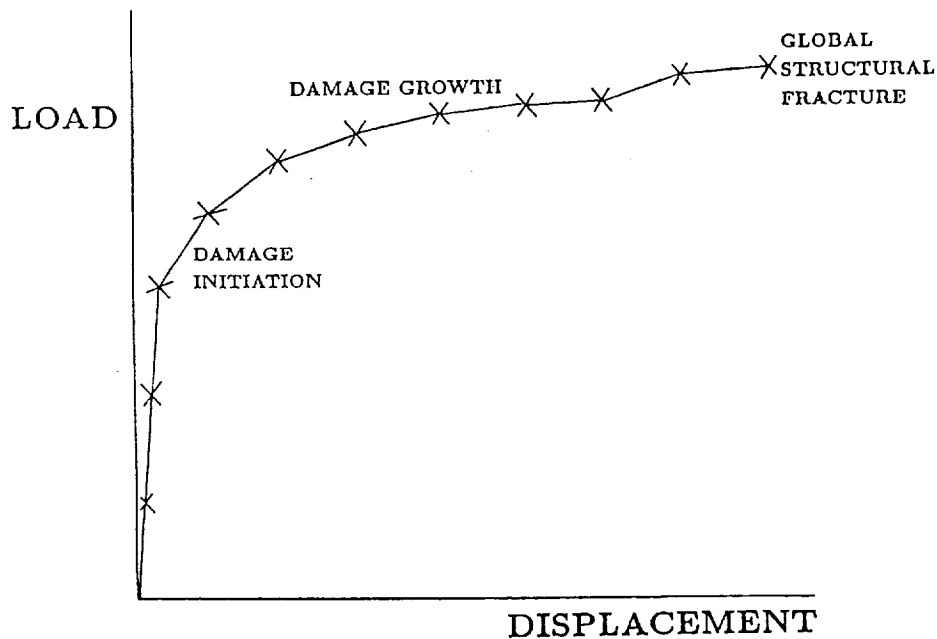
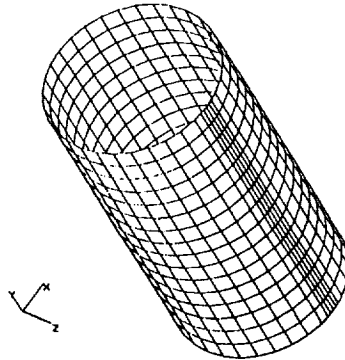


Figure 3 - Overall Codstran Simulation Displacement

SHELL STRUCTURES EVALUATED

An illustrative example of CODSTRAN's effectiveness is the composite shell shown in Fig. 4. This composite shell has surface and mid-thickness defects (cut plies) as shown in Fig. 5. The progressive fracture results obtained for internal pressure are presented in Fig. 6. The shell with surface defects exhibits the most progressive damage to fracture. The shell without defects exhibits some progressive damage to fracture while the shell with the mid-thickness defects exhibits no progressive damage and has the lowest burst pressure. These three cases demonstrate that CODSTRAN can readily be used to evaluate defect-location effects on composite structural fracture.



Composite Shell T300/Epoxy $[90_2/\pm 15/90_2/\pm 15/90_2/\mp 15/90_2]$

shell diameter = 40 in. length = 80 in.

612 nodes, 576 quadrilateral elements

initial fiber defect in 2 adjacent hoop plies

defect extends 5 in. along axial direction of shell

Figure 4 - Shell Structures Schematic

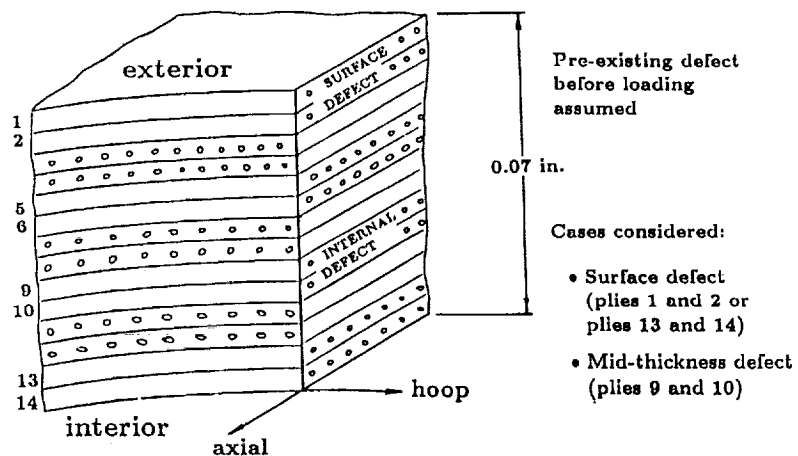


Figure 5 - Composite Shell T300/Epoxy $[90_2/\pm 15/90_2/\pm 15/90_2/\mp 15/90_2]$

CODSTRAN SIMULATION RESULTS

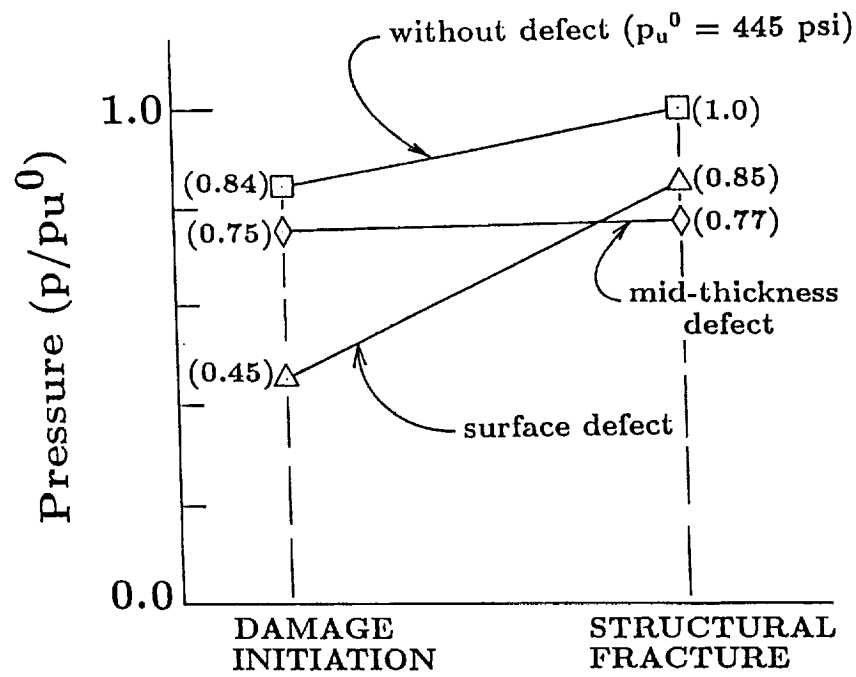
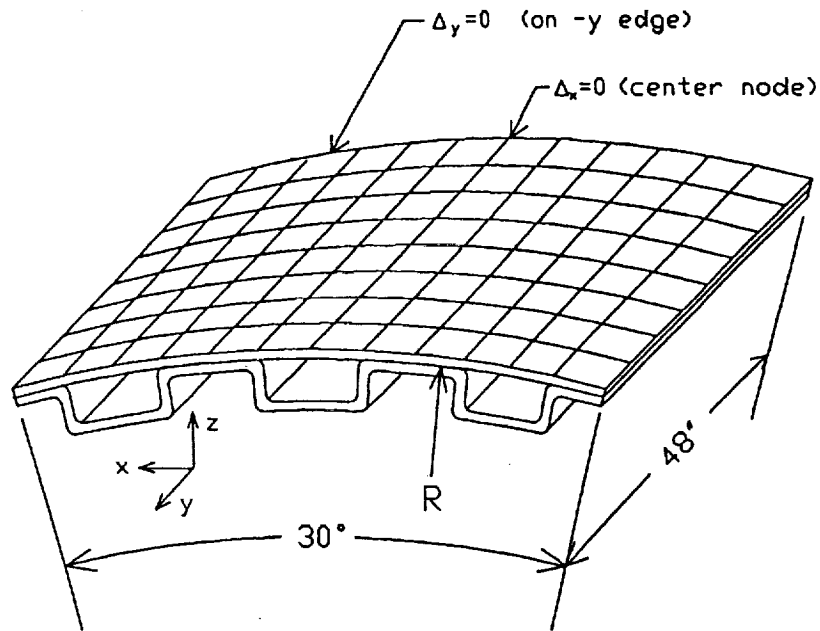


Figure 6 - Summary of Results for Composite Shell
Composite Shell T300/Epoxy[90₂/±15/90₂/±15/90₂/±15/90₂]

STIFFENED COMPOSITE CYLINDRICAL SHELL PANEL

Another illustrative example is the application of CODSTRAN to built-up composite structures depicted in Fig. 7. The laminate configuration is shown in Fig. 8. The progressive fracture results obtained for different loading conditions are summarized in Figs. 9 and 10. This composite structure exhibits the most extensive damage when subjected to tensile load and the least when subjected to combined loads. Internal pressure increases the load as well as the extent of the progressive damage.

This illustrative example demonstrates that complex composite structures subjected to different loading conditions can be evaluated for progressive fracture and up to structural fracture by using CODSTRAN.



NOTE: $\theta_y = 0$ (all edge nodes)
 $\Delta_{\text{radial}} = 0$ (all edge nodes)

Figure 7 - Stiffened Composite Cylindrical Shell Panel Schematic

BUILT-UP COMPOSITE STRUCTURES

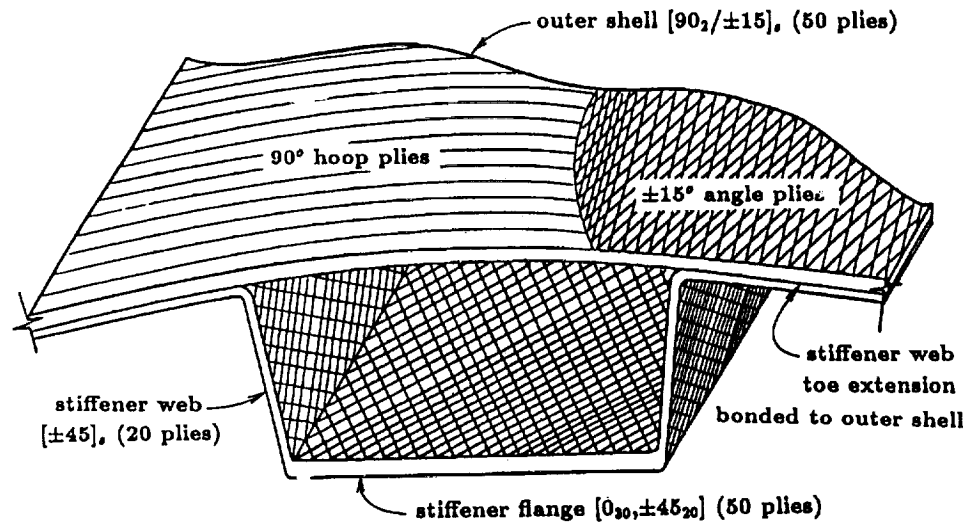


Figure 8 - Schematic of Laminate Structure

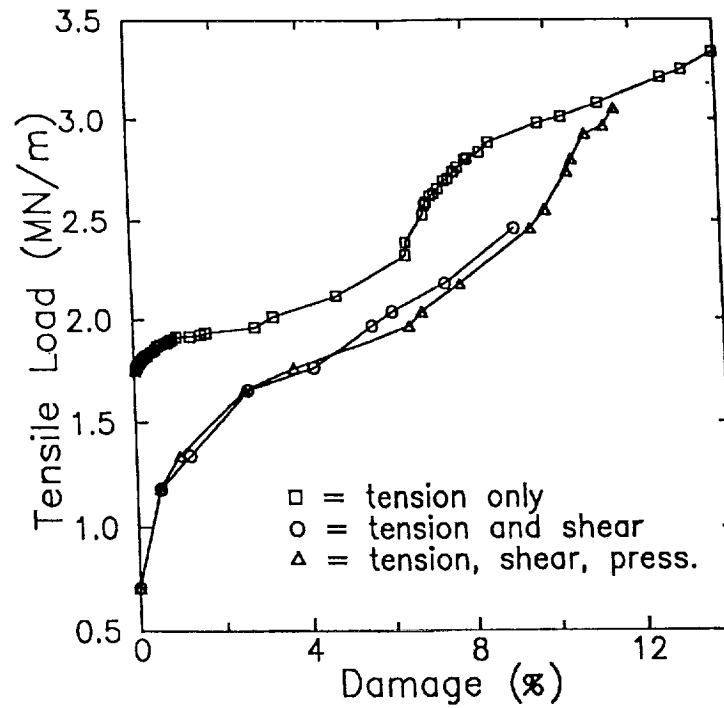


Figure 9 - Axial Tension Load and Damage Progression

IPACS RESULTS FOR BUILT-UP COMPOSITE STRUCTURES

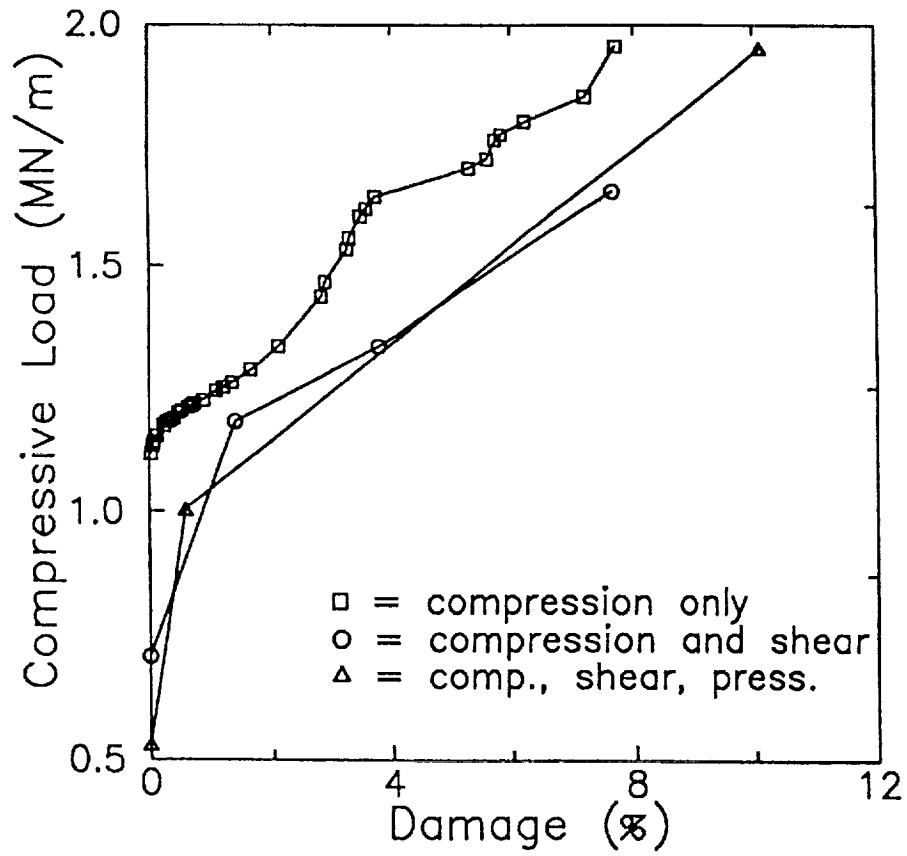
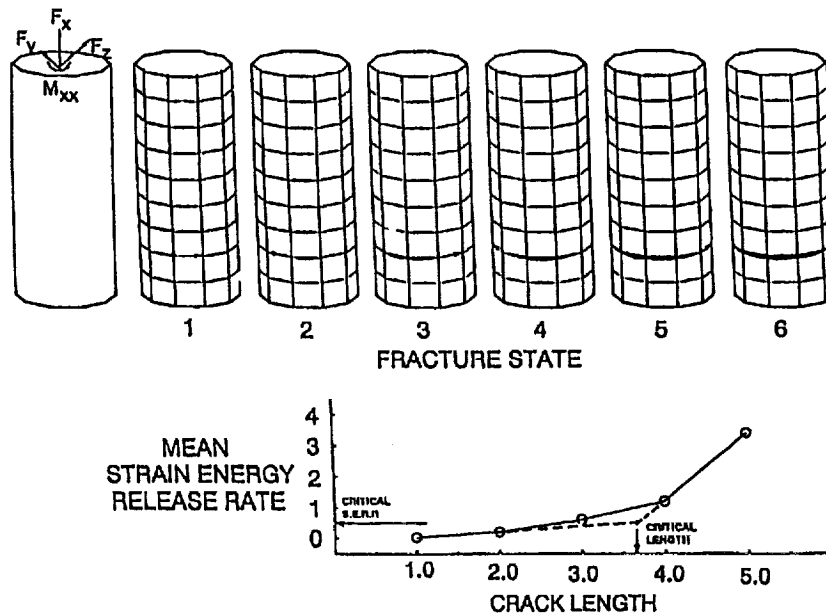


Figure 10 - Axial Compression Load and Damage Progression

GENERALIZATION

The general procedure to simulate progressive fracture in composite structures by using CODSTRAN is outlined in Fig. 11. Progressive fracture provides information for (1) detrimental defect size, (2) qualification inspection and retirement-for-cause criteria, and (3) developing and implementing fracture control plans.



Computational simulation of structural fracture

- Develop global finite element structural/stress analysis model
- Apply spectra loads
- Identify hot spots for spectra loads
- Introduce flaws
- With spectra loads on structure grow flaws
- Monitor structural performance degradation versus flaw growth
- Identify flaw size for unacceptable performance degradation
- Set qualification, inspection and retirement-for-cause criteria

Figure 11 - Generalization Procedure

HIERARCHICAL COMPUTATIONAL SIMULATION/TAILORING OF HOT COMPOSITE LAMINATES/STRUCTURES

The hierarchical simulation/tailoring of hot composite laminates and structures is performed by the use of several function-specific computer codes summarized in Fig. 12, where the computational capabilities, general input, code names and specific objectives are described.

Reference: Chamis, C. C., Murthy, P. L. N. and Singhal, S. N., "Computational Simulation of Hot Composite Structures," NASA TM 103681, January 1991.

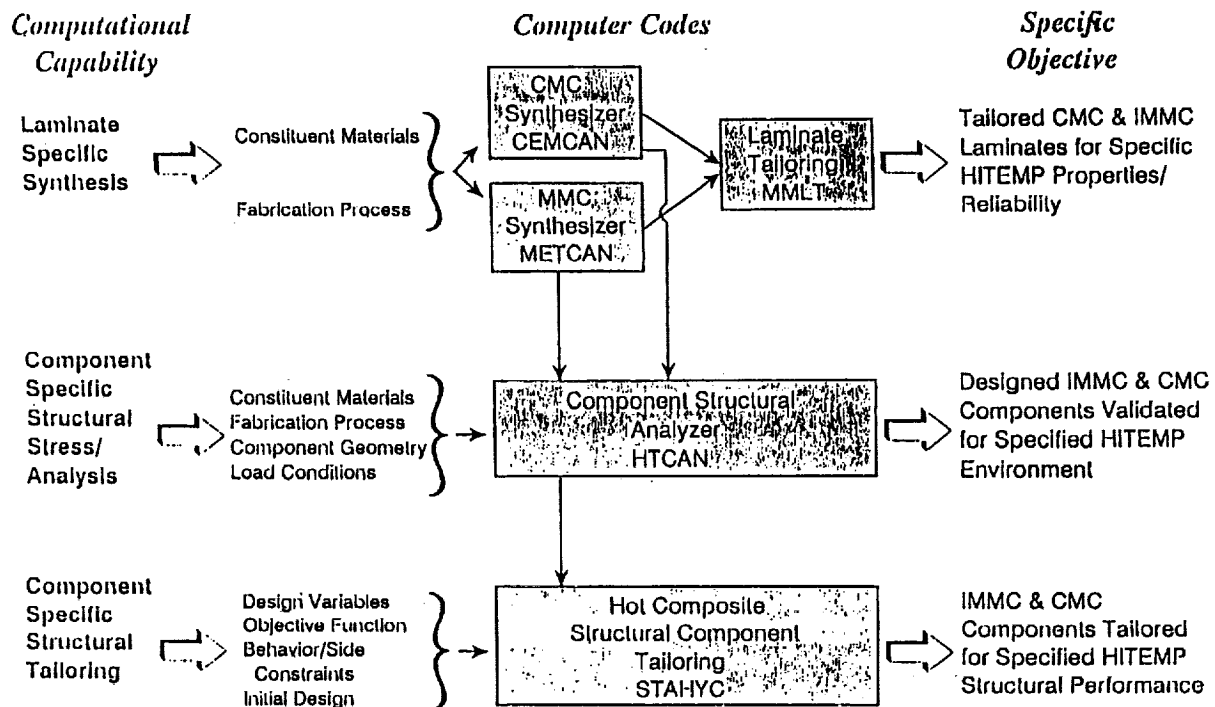


Figure 12 - Hierarchical Computational Simulation/Tailoring of Hot Composite Laminates/Structures (Computer Codes - Description)

HITCAN: AN INTEGRATED APPROACH FOR HOT COMPOSITE STRUCTURES

A block diagram of the HITCAN computer code is shown in Fig. 13. It includes two independent computer codes: (1) METCAN (Metal Matrix Composite Analyzer) for the nonlinear metal matrix composite mechanics, and (2) MHOST, a dedicated finite element computer code for nonlinear finite element structural analysis. The nonlinear material behavior in HITCAN is represented by a multifactor relationship described in Fig. 14.

Reference: Singhal, S. N., Lackney, J. J., Chamis, C. C. and Murthy, P. L. N., "Demonstration of Capabilities of High Temperature Composite Analyzer Code HITCAN," NASA TM-102560, March 1990.

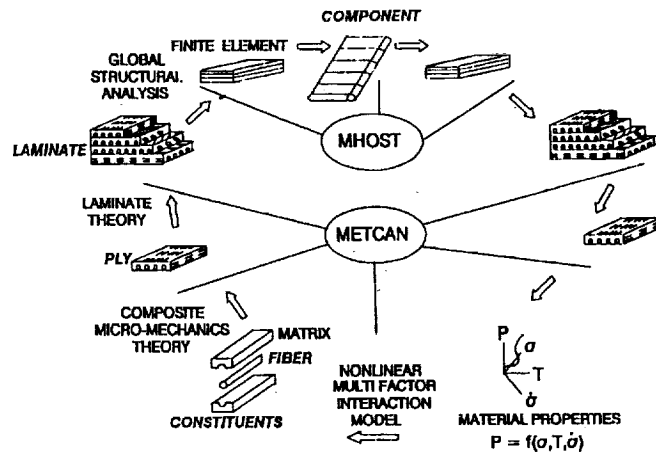


Figure 13 - HITCAN: An Integrated Approach for Hot Composite Structures

$$\frac{s_n}{s_o} = \left[\frac{T_c - T_u}{T_c - T_o} \right]^n \left[\frac{s_F - \sigma_M}{s_F - \sigma_o} \right]^m \left[\frac{N_{MF} s_F - N_M \sigma_{Mc}}{N_{MF} s_F} \right]^p \left[\frac{N_{TF} s_F - N_T \sigma_{Tc}}{N_{TF} s_F} \right]^q \left[\frac{t_F s_F - t \sigma_M}{t_F s_F} \right]^r$$

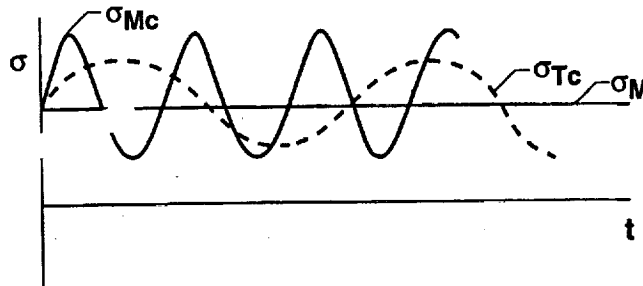
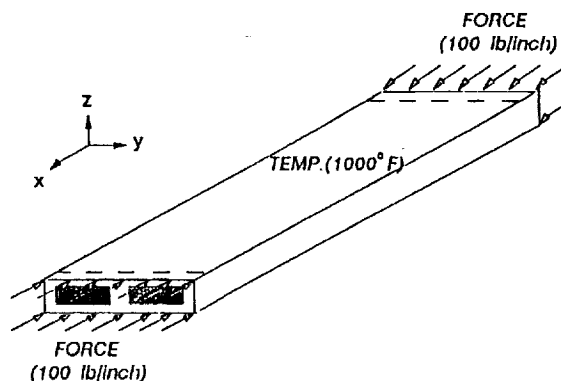


Figure 14 - Multifactor Relationship for Estimating Life

DEMONSTRATION: ACTIVELY COOLED HOT-COMPOSITE PANEL BUCKLING

Application of HITCAN to determine the buckling resistance of an actively-cooled panel is shown in Fig. 15. Fiber degradation (interaction with the matrix at high temperatures) decreases the buckling resistance of the panel as would be expected. Combined thermomechanical loading decreases the buckling resistance as well. This type of hot composite structure evaluation is only possible by the kind of hierarchical simulation integrated in HITCAN.

Simply Supported-Free Actively-Cooled Structure under axial & uniform Temp. Load
for (SiC/Ti-15-3-3-3, Top:[90,0]_S Bottom:[90]_S, Spars:4[0]_S); 0.4 FVR



CRITICAL BUCKLING FORCE

- (i) UNDER MECHANICAL LOADING ONLY = 2950 lb/inch
- (ii) WITH FIBER DEGRADATION, UNDER MECHANICAL LOADING ONLY = 2850 lb/inch
- (iii) UNDER THERMO-MECHANICAL LOADING = 2720 lb/inch

Figure 15 - Demonstration: Actively Cooled Hot-Composite Panel Buckling
(Without and With Combined Loads)

DEMONSTRATION: ACTIVELY COOLED HOT-COMPOSITE PANEL - RESULT

The corresponding displacements and micro-region stresses in the actively-cooled hot-composite panel (Fig. 15) are shown in Fig. 16. The fiber stress increases as the load increases while the matrix stress decreases and the stress in the interphase remains about the same. The fibers are the main load carrying members at these high temperatures which is the primary purpose for putting them there in the first place.

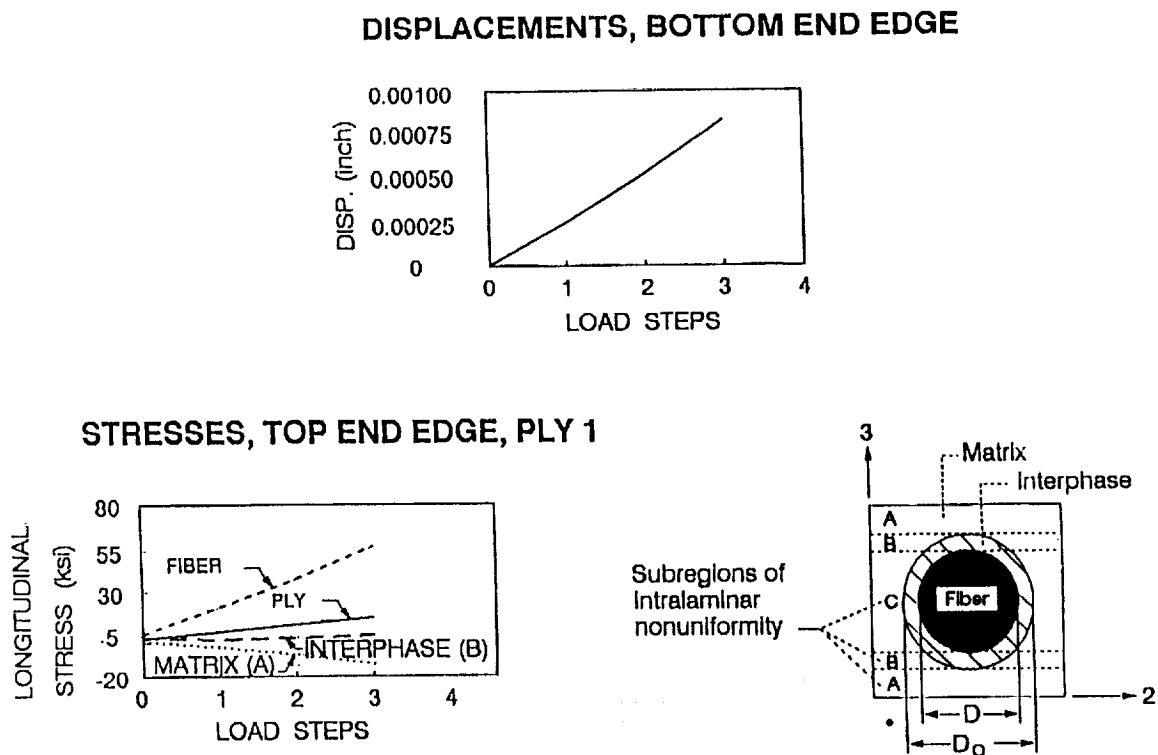


Figure 16 - Demonstration: Actively Cooled Hot-Composite Displacements and Microstresses

APPROACH: INTEGRATED PROBABILISTIC ASSESSMENT OF COMPOSITE STRUCTURES

The computer code IPACS (Integrated Probabilistic Assessment of Composite Structures) is depicted schematically in Fig. 17. It consists of combining two different codes: Probabilistic composite mechanics and probabilistic finite element structural analysis. The combination of these two codes provides the capability to simulate various uncertainties associated with composite structures from constituent material properties to structural description.

Reference: Shiao, M. C. and Chamis, C. C., "Probabilistic Evaluation of Fuselage-Type Composite Structures," NASA TM-105881, November 1992.

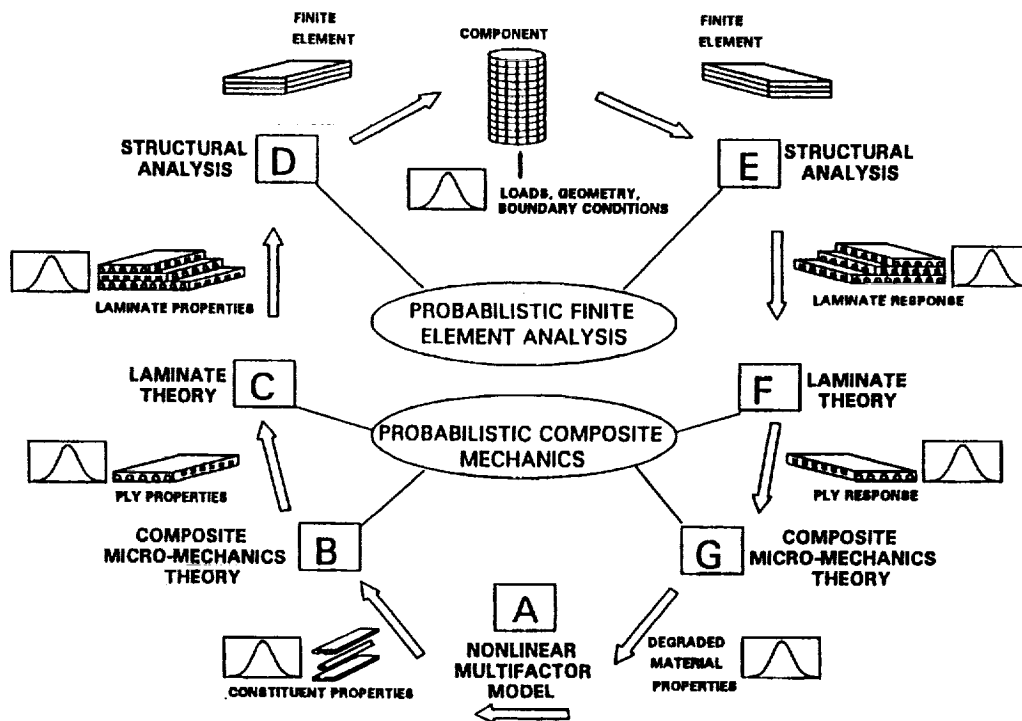


Figure 17 - Approach: Integrated Probabilistic Assessment of Composite Structures Simulation Diagram

IPACS ASSESSMENT OF A COMPOSITE WING

The composite structure shown in Fig. 18 is selected as a sample case to illustrate application of the IPACS computer code. The various uncertainties included are summarized in the figure.

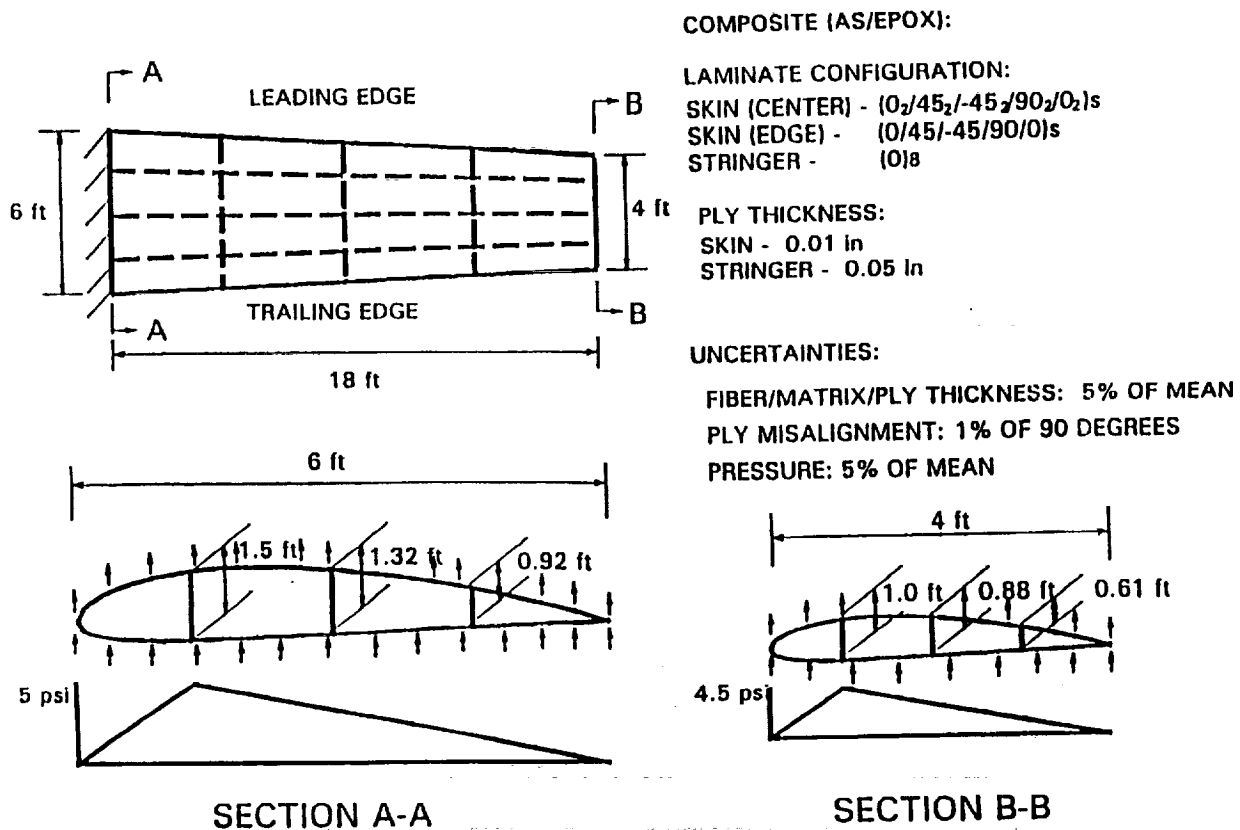


Figure 18 - Geometry and Loading for a Composite Wing

COMPRESSIVE FATIGUE LIFE OF A COMPOSITE WING

The fatigue life results obtained by using IPACS for the composite wing are shown in Fig. 19. The sensitivity factors that influence the fatigue life are also shown. The probability of fatigue failure increases exponentially with fatigue cycles. Two wings in ten thousand will fail in one-hundred-thousand fatigue cycles. Another important aspect of the probabilistic assessment is the evaluation of the sensitivity factors. These are shown in the lower part of Fig. 19. Only eight of the about one-hundred factors influence fatigue life.

This multitude of sensitivity factors illustrate the difficulty associated with predicting fracture in composite structures by using classical or traditional approaches. The composite wing probabilistic assessment demonstrates that the development of IPACS has matured sufficiently to be effectively used in aeronautics composite structures of practical significance.

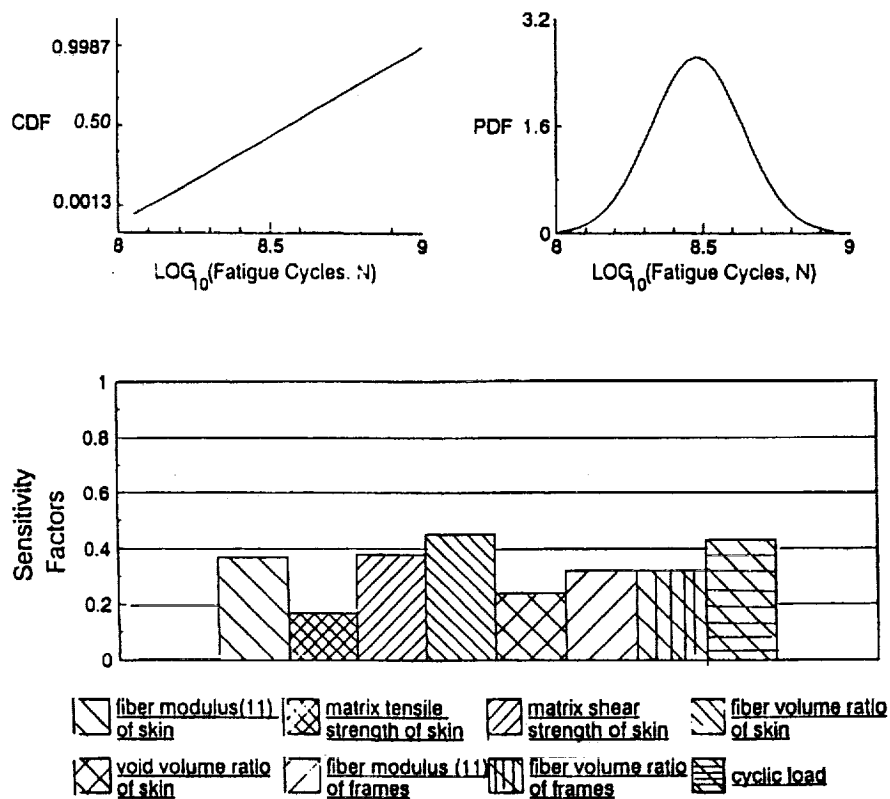


Figure 19 - Compressive Fatigue Life: Probabilistic Distributions and Sensitivity Factors

SUMMARY OF RESULTS

- Composite shells with internal defects and subjected to internal pressure exhibit no damage growth prior to fractures.
- The hierarchical simulation for high-temperature composite structures behavior accurately simulated fracture in a SiC/Ti ring.
- The IPACS computer code simulates uncertainties/sensitivities in evaluating life/reliability of composite wing-type structures.

CONCLUSION

Three parallel computational simulation methods are being developed at the LeRC SMB for composite structures failure and life analysis:

- Progressive fracture CODSTRAN
- Hierarchical methods for high-temperature composites
- Probabilistic evaluation

Results to date demonstrate that these methods are effective in simulating composite structures failure/life/reliability.

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